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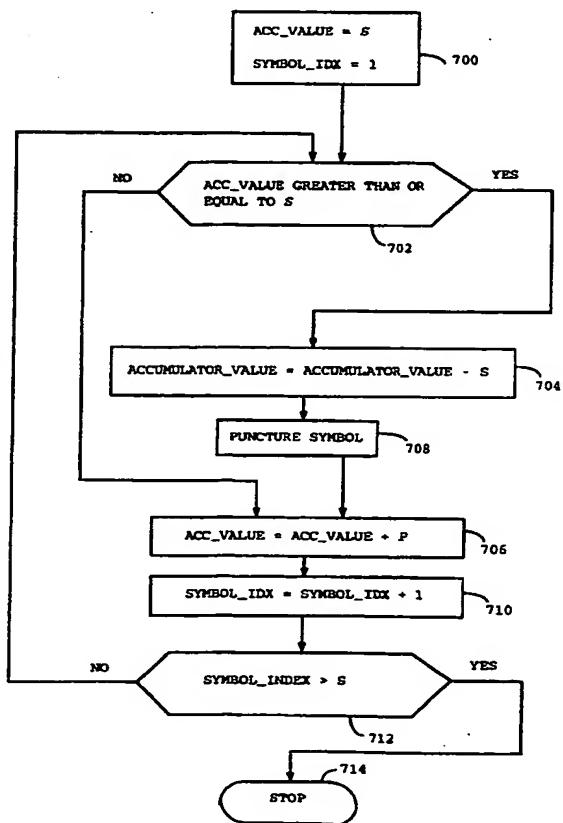
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(54) Title: METHOD AND APPARATUS FOR PUNCTURING CODE SYMBOLS IN A COMMUNICATIONS SYSTEM



(57) Abstract: Techniques for puncturing symbols in a communications system. S symbols are received for a frame having a capacity of N symbols, with S being greater than N. P symbols need to be punctured so that remaining symbols fit into the frame. A number of puncture distances, D1 through DN, are computed based on S and P. A particular number of symbol punctures is determined for each computed puncture distance. P1 through PN symbol punctures are then performed at the distances of D1 through DN, respectively. For a more even distribution of the symbol punctures, each of the distances D1 through DN can be selected to be greater than or equal to a minimum puncture distance Dmin defined as $D_{min} = \lceil \frac{S}{P} \rceil$, where $\lceil \cdot \rceil$ denotes a floor operator. The symbol punctures at each computed distance can be performed together or distributed with symbol punctures at other distances. In the alternative, an accumulator is configured to wrap around after it has been incremented to a value of S, each increment being of size P. A symbol index is incremented by one each time the accumulator is incremented by P, until the symbol index exceeds the value S. The process is advantageously begun with a puncture. Each time the accumulator wraps around, another puncture is performed.

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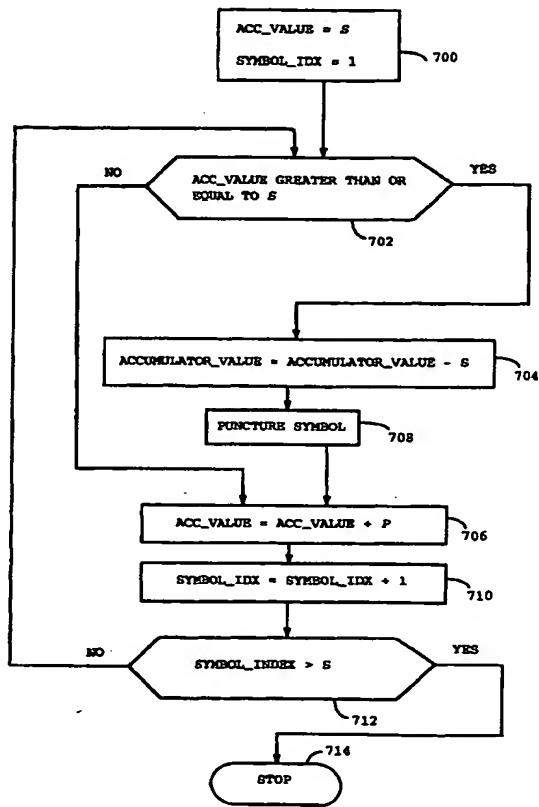
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(54) Title: METHOD AND APPARATUS FOR PUNCTURING CODE SYMBOLS IN A COMMUNICATIONS SYSTEM



(57) Abstract: Techniques for puncturing symbols in a communications system. S symbols are received for a frame having a capacity of N symbols, with S being greater than N. P symbols need to be punctured so that remaining symbols fit into the frame. A number of puncture distances, D1 through DN, are computed based on S and P. A particular number of symbol punctures is determined for each computed puncture distance. P1 through PN symbol punctures are then performed at the distances of D1 through DN, respectively. For a more even distribution of the symbol punctures, each of the distances D1 through DN can be selected to be greater than or equal to a minimum puncture distance Dmin defined as $D_{min} = \lceil \frac{S}{P} \rceil$, where $\lceil \cdot \rceil$ denotes a floor operator. The symbol punctures at each computed distance can be performed together or distributed with symbol punctures at other distances. In the alternative, an accumulator is configured to wrap around after it has been incremented to a value of S, each increment being of size P. A symbol index is incremented by one each time the accumulator is incremented by P, until the symbol index exceeds the value S. The process is advantageously begun with a puncture. Each time the accumulator wraps around, another puncture is performed.

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METHOD AND APPARATUS FOR PUNCTURING CODE SYMBOLS IN A COMMUNICATIONS SYSTEM

BACKGROUND OF THE INVENTION

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I. Field of the Invention

The present invention relates to data communications. More particularly, the present invention relates to a method and apparatus for puncturing code symbols to provide improved performance in a communications system.

II. Description of the Related Art

15 In a typical digital communications system, data is processed, modulated, and conditioned at a transmitter unit to generate a modulated signal that is then transmitted to one or more receiver units. The data processing may include, for example, formatting the data into a particular frame format, encoding the formatted data with a particular coding scheme to
10 provide error detection and/or correction at the receiver unit, puncturing (i.e., deleting) some of the code symbols to fit within a particular frame size, channelizing (i.e., covering) the encoded data, and spreading the channelized data over the system bandwidth. The data processing is typically defined by the system or standard being implemented.

20 At the receiver unit, the transmitted signal is received, conditioned, demodulated, and digitally processed to recover the transmitted data. The processing at the receiver unit is complementary to that performed at the transmitter unit and may include, for example, despreading the received samples, recovering the despread samples, inserting "erasures" in place of
25 punctured symbols, and decoding the symbols to recover the transmitted data.

30 A digital communications system typically employs a convolutional code or a Turbo code to provide error correction capability at the receiver unit. The ability to correct transmission errors enhances the reliability of a data transmission. Conventionally, convolutional and Turbo coding is performed
35 using a particular polynomial generator matrix that generates a particular number of code symbols (e.g., 2, 3, or more code symbols) for each input data

selecting the puncture distances, and using the selected distances at the appropriate time, the desired puncture results can be achieved.

- An embodiment of the invention provides a method for puncturing symbols in a communications system (e.g., a system that conforms to CDMA-2000, W-CDMA, or 1XTREME standard, which are identified below). In accordance with the method, S symbols are received for a frame having a capacity of N symbols, with S being greater than N . P symbols need to be punctured from the S received symbols such that the remaining unpunctured symbols fit into the frame. A number of puncture distances, D_1 through D_N , are then computed based on the S received symbols and the P symbol punctures. Next, a particular number of symbol punctures is determined for each computed puncture distance. P_1 through P_N symbol punctures are then performed at the puncture distances of D_1 through D_N , respectively. For a more even distribution of the symbol punctures, each of the distances D_1 through D_N can be selected to be greater than or equal to a minimum puncture distance D_{min} defined as:

$$D_{min} = \left\lfloor \frac{S}{P} \right\rfloor, \text{ where } \lfloor \quad \rfloor \text{ denotes a floor operator.}$$

In a simple implementation, two puncture distances, D_1 and D_2 , can be computed based on S and P as follows:

$$20 \quad D_1 = \left\lfloor \frac{S}{P} \right\rfloor, \quad \text{and}$$

$$D_2 = \begin{cases} D_1 & \text{if } D_1 * P = S \\ D_1 + 1 & \text{otherwise.} \end{cases}$$

P_1 and P_2 can then be computed as:

$$P_2 = S - P * D_1, \text{ and}$$

$$P_1 = P - P_2.$$

- 25 The symbol puncturing can be achieved by (1) selecting either the puncture distance of D_1 or D_2 to be used to determine which symbol should be punctured next, (2) puncturing the next symbol based on the selected puncture

Yet another embodiment of the invention provides a transmit data processor for use in a communications system. The transmit data processor includes an encoder coupled to a symbol puncturing element. The encoder receives and codes data bits to generate code symbols. The symbol puncturing element (1) receives S symbols for a frame having a capacity of N symbols, with S being greater than N , (2) determines P symbols to be punctured from the S received symbols such that the remaining unpunctured symbols fit into the frame, (3) computes the puncture distances of D_1 through D_N based on S and P , (4) determines P_1 through P_N symbol punctures to be performed at the distances of D_1 through D_N , respectively, and (5) performs P_1 through P_N symbol punctures on the S received symbols at the puncture distances of D_1 through D_N , respectively. The symbol puncturing element can be designed to implement various features described above (e.g., distribute the P_1 and P_2 punctures over the entire frame). Again, each of the puncture distances of D_1 through D_N can be selected to be greater than or equal to a minimum puncture distance D_{min} defined above.

The transmit data processor can further include a symbol repeating element that couples to the encoder and the symbol puncturing element. The symbol repeating element receives the code symbols from the encoder and repeats each received code symbol M times to generate the S symbols, with M being an integer greater than or equal to one.

Yet another embodiment of the invention provides a receiver unit for use in a communications system. The receiver unit includes a receiver, a demodulator, and a receive data processor coupled in cascade. The receiver receives and processes a modulated signal to provide a number of samples for each received frame. The demodulator processes the samples to provide N symbols for each received frame. The receive data processor (1) receives the N symbols, (2) determines that P symbol punctures had been performed on S symbols to generate the N received symbols, (3) computes a number of puncture distances, D_1 through D_N , based on S and P , (4) determines P_1 through P_N symbol punctures that had been performed at the distances of D_1 through D_N , respectively, (5) derives a puncturing pattern (e.g., based on D_1 through D_N , and P_1 through P_N) used to puncture the S symbols to generate the N received symbols, (6) inserts P erasures among the N received symbols in accordance with the derived puncturing pattern to generate S recovered symbols, and (7) decodes the S recovered symbols with a particular decoding scheme.

number S from an accumulator value if the accumulator value is greater than or equal to the number S ; (d) puncturing a symbol; (e) incrementing the accumulator value by the number P ; and (h) repeating steps (c)-(e) a number of times that is equal to the number S .

- 5 Other aspects and embodiments of the invention are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

10 The features, nature, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. 1 is a simplified block diagram of a communications system in which the present invention may be implemented;

15 FIG. 2 is a block diagram of a transmit data processor that can be designed to implement some embodiments of the present invention;

FIG. 3A is a flow diagram of a conventional symbol puncturing technique, which is described in the CDMA-2000 standard;

20 FIGS. 3B and 3C are diagrams that show two simple puncturing examples using the conventional symbol puncturing technique described in FIG. 3A;

FIG. 4A is a flow diagram of an embodiment of a symbol puncturing technique of the present invention;

25 FIG. 4B is a diagram that shows a puncturing example using the symbol puncturing technique described in FIG. 4A;

FIG. 5A is a flow diagram of an embodiment of another symbol puncturing technique of the present invention;

FIG. 5B is a diagram that shows a puncturing example using the symbol puncturing technique described in FIG. 5A; and

30 FIG. 6 shows plots of the performance achieved with the conventional puncturing technique versus the puncturing technique of the present invention.

FIG. 7 is a flowchart of an alternative method of puncturing symbols.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

35

FIG. 1 is a simplified block diagram of an embodiment of a communications system 100 in which the present invention may be

APPARATUS FOR HIGH RATE PACKET DATA TRANSMISSION," filed November 3, 1997 (hereinafter referred to as the HDR system). These patents and patent application are assigned to the assignee of the present invention and incorporated herein by reference.

- 5 CDMA systems are typically designed to conform to one or more standards such as the "TIA/EIA/IS-95-A Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System" (hereinafter referred to as the IS-95-A standard), the "TIA/EIA/IS-98 Recommended Minimum Standard for Dual-Mode Wideband Spread Spectrum
- 10 Cellular Mobile Station" (hereinafter referred to as the IS-98 standard), the standard offered by a consortium named "3rd Generation Partnership Project" (3GPP) and embodied in a set of documents including Document Nos. 3G TS 25.211, 3G TS 25.212, 3G TS 25.213, and 3G TS 25.214 (hereinafter referred to as the W-CDMA standard), and the "TR-45.5 Physical Layer Standard for
- 15 cdma2000 Spread Spectrum Systems" (hereinafter referred to as the CDMA-2000 standard). New CDMA standards are continually proposed and adopted for use. These CDMA standards are incorporated herein by reference.

FIG. 2 is a block diagram of an embodiment of TX data processor 114, which can be designed to implement some embodiments of the present invention. Traffic data is received (again, typically in frames or packets) by a frame formatter 212 that formats each received frame in a particular manner. For example, frame formatter 212 can perform cycle redundancy check (CRC) coding on each frame of data and append the CRC bits to the frame. Frame formatter 212 typically further adds a number of code-tail bits to the end of each frame. The code-tail bits typically have values of zero and are used to set the subsequent encoder to a known state (e.g., all zeros) after the frame has been coded. Other frame formatting functions may also be performed by frame formatter 212.

The formatted frames are then provided to an encoder 214 that codes each frame with a particular coding scheme to generate a corresponding frame of code symbols. For example, encoder 214 may perform convolutional or Turbo coding of a data frame. The particular coding scheme used is dependent on the particular system or standard being implemented and may be selectable (e.g., different coding schemes may be used for different types of services). The coding schemes used for the CDMA-2000 and W-CDMA systems are described in detail in the aforementioned standard documents.

before the next puncture. In accordance with the CDMA-2000 standard, the puncture distance D is computed as:

$$D = \left\lfloor \frac{S}{P} \right\rfloor, \quad \text{Eq (1)}$$

- where the symbol " $\lfloor \cdot \rfloor$ " denotes the floor operator, which provides the next lower integer. For example, if $S/P = 5.2$, then $\lfloor S/P \rfloor = 5$.

Symbols in the frame are then punctured using the computed distance D . To perform a symbol puncture, symbols in the frame are counted, starting with the first symbol, and the D^{th} symbol is punctured, at step 316. After a symbol has been punctured, the number of required punctures P is decremented, at step 318. A determination is then made whether all P symbols have been punctured, at step 320. This determination can be made by simply checking whether $P = 0$. If all P symbols have been punctured, the process terminates. Otherwise, the process returns to step 316 and another symbol is punctured, again based on the previously computed distance D .

The conventional symbol puncturing technique described in FIG. 3A can provide varied punctured results, depending on the particular values of S and P . Specifically, the punctured symbols may be evenly distributed throughout the frame for some values of S and P , or may be concentrated in one portion of the frame for some other values of S and P . These varied punctured results can be illustrated by the following simple examples.

FIG. 3B is a diagram that illustrates a simple example using the conventional symbol puncturing technique described in FIG. 3A. In this specific example, 30 symbols are generated (i.e., $S = 30$) but (for this example) only 20 symbols can be fitted into a frame (i.e., $N = 20$). Thus, 10 symbols need to be punctured (i.e., $P = S - N = 30 - 20 = 10$). Using equation (1), the puncture distance D can be computed as 3. As shown in FIG. 3B, every 3rd symbol is punctured, as represented by the boxes with the X. In this specific example, the punctured symbols are uniformly distributed across the entire frame.

FIG. 3C is a diagram that illustrates another simple example using the conventional symbol puncturing technique, but for different values of S and P . In this specific example, 31 symbols are generated (i.e., $S = 31$) and 20 symbols may be fitted into a frame (i.e., $N = 20$). Thus, 11 symbols need to be punctured (i.e., $P = 11$). Using equation (1), the puncture distance D can be computed as 2. As shown in FIG. 3C, every 2nd symbol is punctured, as represented by the boxes with the X, until all 11 symbols have been punctured. After the 11th

- whether all P symbols have been punctured, at step 420. Again, this determination can be made by simply checking whether $P = 0$. If all P symbols have been punctured, the process terminates. Otherwise, the process returns to step 414 and the puncture distance D is recomputed based on the updated values for S and P . Symbols are counted from there onwards and the D^{th} symbol is punctured, at step 416. The process then continues until all P symbols have been punctured.

- The symbol puncturing technique shown in FIG. 4A recomputes the puncture rate (i.e., the puncture distance D) in "real-time" after each puncture.
- 10 The new "puncture distance" (i.e., the number of symbols until the next puncture) is computed based on the number of symbols still remaining and the number of punctures still to be performed. Each computation generates a new puncture distance D that attempts to uniformly distribute the remaining symbol punctures.
- 15 For a clearer understanding, the puncturing technique described in FIG. 4A can be applied to the example shown in FIG. 3B in which 31 code symbols are generated (i.e., $L = 31$) and the frame has a capacity of 20 symbols (i.e., $N = 20$). Again, 11 symbol punctures are required. Table 1 lists the parameters S , P , and D for each puncture (i.e., for each pass through the loop shown in FIG. 20 4A).

Table 1

Parameters	S	P	D
start	31	11	$D = \lfloor 31/11 \rfloor = 2$
After 1 st puncture	29	10	$D = \lfloor 29/10 \rfloor = 2$
After 2 nd puncture	27	9	$D = \lfloor 27/9 \rfloor = 3$
After 3 rd puncture	24	8	$D = \lfloor 24/8 \rfloor = 3$
After 4 th puncture	21	7	$D = \lfloor 21/7 \rfloor = 3$
After 5 th puncture	18	6	$D = \lfloor 18/6 \rfloor = 3$
After 6 th puncture	15	5	$D = \lfloor 15/5 \rfloor = 3$
After 7 th puncture	12	4	$D = \lfloor 12/4 \rfloor = 3$
After 8 th puncture	9	3	$D = \lfloor 9/3 \rfloor = 3$
After 9 th puncture	6	2	$D = \lfloor 6/2 \rfloor = 3$
After 10 th puncture	3	1	$D = \lfloor 3/1 \rfloor = 3$

FIG. 4B is a diagram that shows the results of the puncturing example described in Table 1. For the first two punctures, the distance is computed as

$$S = P1 \cdot D1 + P2 \cdot D2 .$$

Eq (7)

- Once the puncture distances $D1$ and $D2$ and the number of punctures $P1$ and $P2$ have been computed, one of the computed puncture distances is selected, at step 518. Various methods can be used to select either $D1$ or $D2$, as 5 described below. A symbol in the frame is then punctured using the selected puncture distance. Again, to perform a symbol puncture, symbols in the frame are counted, starting with first symbol in the frame or the last punctured symbol, and the $D1^{\text{th}}$ or $D2^{\text{th}}$ symbol is punctured, at step 520. After a symbol has been punctured, the required number of punctures $P1$ or $P2$ is decremented, 10 depending on which puncture distance has been selected, at step 522. Specifically, $P1$ is decremented if $D1$ is selected and $P2$ is decremented if $D2$ is selected.

- A determination is then made whether all $P1$ and $P2$ symbols have been punctured, at step 524. This determination can be made by simply checking 15 whether $P1 = 0$ and $P2 = 0$. If all $P1$ and $P2$ symbols have been punctured, the process terminates. Otherwise, the process returns to step 518 and one of the puncture distances is selected. The process then continues until all $P1$ and $P2$ symbols have been punctured.

- For a better understanding, the puncturing technique described in FIG. 20 5A can be applied to the specific example described above in which 31 symbols are generated (i.e., $S = 31$), 20 symbols may be fitted into a frame (i.e., $N = 20$), and 11 symbols need to be punctured (i.e., $P = 11$). Using equations (3) and (4), the puncture distances $D1$ and $D2$ can be computed as:

$$D1 = \lfloor 31/11 \rfloor = 2, \text{ and}$$

$$25 \quad D2 = \lceil 31/11 \rceil = 3,$$

respectively. Using equations (5) and (6), the number of punctures at distances $D2$ and $D1$ can be computed as:

$$P2 = 31 - 11 \lfloor 31/11 \rfloor = 9, \text{ and}$$

$$P1 = 11 - 9 = 2,$$

- 30 respectively. Thus, two punctures are performed at the distance of two and nine punctures are performed at the distance of three.

As noted above, various methods can be used to select which one of the puncture distances, $D1$ or $D2$, to use for the next puncture. In one embodiment,

before each puncture, the accumulation value A is added to the value in the accumulator and stored back to the accumulator. If the accumulator wraps around after the accumulation with the value A , then the puncture distance corresponding to the smaller $P1$ or $P2$ value is selected for the next symbol puncture.

For the above example, the values in the accumulator can be computed as 227, 454, 681, 908, 111, 338, 565, 792, 1019, 222, and 449, before the 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, and 11th symbol punctures, respectively. The puncture distance $D1$ is selected for the 5th and 10th symbol punctures since the 10 accumulator has wrapped around and has values of 111 and 222, respectively. By initializing the accumulator with a value other than zero, the first puncture at the distance of two can be different. For example, if the accumulator is initialized at the value of 512, then the 3rd and 7th punctures are performed at the distance of two and the remaining punctures are performed at the distance of 15 three.

For the embodiment shown in FIG. 5A, the computational costs are maintained low. Specifically, only one division operation is performed at step 514 to compute the puncture distances $D1$ and $D2$, which is the same number of division operation as for the conventional puncturing technique shown in FIG. 20 3A. Thus, the embodiment shown in FIG. 5A provides improved performance at equivalent computation costs.

FIG. 5B is a diagram that shows the results of the puncturing example described above using the symbol puncturing technique shown in FIG. 5A. In this diagram, the 1st and 6th punctures are performed using the distance of two 25 and the other punctures are performed using the distance of three. The punctures at distances $D1$ and $D2$ can also be distributed in various other manners, some of which are described above.

The symbol puncturing technique of the invention described in FIG. 5A can be generalized to cover N puncture distances. The N puncture distances $D1$ 30 through DN can be computed based on S and P (and possibly other parameters) and used to puncture S code symbols. For improved puncturing results (e.g., a more even distribution of the symbol punctures), each of the distances $D1$ through DN can be selected to be greater than or equal to a minimum puncture distance $Dmin$ defined as:

$$35 \quad D_{\min} = \left\lceil \frac{S}{P} \right\rceil. \quad \text{Eq (8)}$$

recovered symbols are then decoded with a particular decoding scheme complementary to the coding scheme used at the transmitter unit.

FIG. 6 shows plots of the performance achieved with the conventional puncturing technique described in FIG. 3A versus the puncturing technique of the invention. The performance results are for the forward link (i.e., from a base station to a user terminal) in the CDMA-2000 system. The horizontal axis represents the number of data and CRC bits for each frame. For the CDMA-2000 system, frames of various sizes are available for use, with the frame sizes being an integer multiple of a basic frame size (e.g., available frame sizes are 5 $768 \bullet K$, where $K = 1, 2, \dots$). The vertical axis represents the average required energy-per-bit-to-total-noise-plus-interference $E_b/(N_0 + I_{oc})$ for a frame error rate (FER) of 1%.

The simulation results for the conventional puncturing technique are shown by a dashed line 610 in FIG. 6. The results indicate some peaks at 15 approximately periodic intervals. For example, peaks are observed at approximately 300, 600, 1200, and 2400 bits. These peaks result from the uneven symbol puncturing generated by the conventional puncturing technique. The peaks represent the need for a higher average energy per bit E_b to maintain the same FER of 1%.

20 The simulation results for the puncturing technique of the invention are shown by a solid line 612 in FIG. 6. The results indicate improvement in performance at some of the peaks. In particular, improvements of approximately 0.5 dB and 1.0 dB are observed at 300 and 600 bits, respectively.

In one embodiment puncturing may be advantageously performed 25 without using numbers of symbol punctures P_1 and P_2 or puncture distances D_1 and D_2 . An accumulator is configured to wrap around after it has been incremented to a value that is greater than or equal to S , each increment being of size P , wherein P is a desired number of symbol punctures, S is a total number of received symbols, and N is a frame capacity in symbols (i.e., a 30 number of symbols remaining after puncturing). The accumulator is thus a modulo- S accumulator. A symbol index is advantageously initialized to one. The symbol index is incremented by one each time the accumulator is incremented by P , until the symbol index reaches the value S . The process is advantageously begun with a puncture. Each time the accumulator wraps 35 around, a puncture is performed. Nevertheless, one of ordinary skill in the art would readily appreciate that the process need not be initiated with a puncture. Additionally, while the accumulator is advantageously initialized to S , those of

SYMBOL_IDX is punctured. Control flow then proceeds to step 706. In step 706 ACC_VALUE is incremented by P (i.e., ACC_VALUE is set equal to the sum of ACC_VALUE and P). Control flow then proceeds to step 710. In step 710 SYMBOL_IDX is incremented by one (i.e., SYMBOL_IDX is set equal to the sum of SYMBOL_IDX and one). Control flow then proceeds to step 714. In step 714 SYMBOL_IDX is compared with the value S . If SYMBOL_IDX is greater than S , control flow proceeds to step 712, at which the process stops. If, on the other hand, SYMBOL_IDX is not greater than S , control flow returns to step 702 and the process continues. In other embodiments SYMBOL_IDX is initialized to the value S and the algorithm terminates when SYMBOL_IDX drops below the one.

In an alternate embodiment, wherein the values S and P have a common denominator M , the value S/M may be substituted for the value S , and the value P/M may be substituted for the value P in the flowchart of FIG. 7 for ACC_VALUE field (but not in the SYMBOL_IDX field). Accordingly, the ACC_VALUE field is initialized to S/M and a modulo- S/M register is used for the accumulator. The accumulator is incremented by P/M each increment. Every time the accumulator value exceeds S/M , a modulo- S/M operation is performed and a symbol puncture is done.

For clarity, some aspects of the invention have been described specifically for the forward link in the CDMA-2000 system. However, the invention can also be used in other communications systems that employ the same, similar, or different puncturing scheme. For example, the invention can be used to perform puncturing in the W-CDMA system and other CDMA systems. Moreover, the symbol puncturing technique of the present invention can also be used on the reverse link (i.e., from the user terminal to the base station). The puncturing techniques of the invention can be modified to be more suited for the specific system or standard in which it is used.

The symbol puncturing techniques of the invention can be implemented in various manners. For example, the puncturing techniques can be implemented in hardware within one or more application specific integrated circuits (ASICs), digital signal processors (DSPs), programmable logic device (PLD), controllers, micro-controllers, microprocessors, other electronic units designed to perform the functions described herein, or a combination thereof. Alternatively, the puncturing techniques of the invention can be implemented in software or firmware executed on a processor or controller. The puncturing

CLAIMS

1. A method for puncturing symbols in a communications system, the
2 method comprising:

4 (a) receiving a number of symbols S to be fitted into a frame having a
capacity of N symbols, wherein S is greater than N ;

6 (b) determining a number of symbols P to be punctured from among the
 S received symbols such that remaining unpunctured symbols fit into the
frame;

8 (c) subtracting the number S from an accumulator value if the
accumulator value is greater than or equal to the number S ;

10 (d) puncturing a symbol;

(e) incrementing the accumulator value by the number P ; and

12 (h) repeating steps (c)-(e) a number of times that is equal to the number
 S .

2. A method for puncturing symbols in a communications system, the
method comprising:

4 receiving a number of symbols S to be fitted into a frame having a
capacity of N symbols, wherein S is greater than N ;

6 determining a number of symbols P to be punctured from among the S
received symbols such that remaining unpunctured symbols fit into the frame;
puncturing a symbol;

8 incrementing a modulo- S accumulator value by the number P a number
of times that is equal to the number S ; and

10 puncturing another symbol each time the modulo- S accumulator value is
decreased.

3. The method of claim 2, further comprising initializing the modulo- S
accumulator value to S before puncturing the first symbol.

4. A transmit data processor for use in a communications system,
comprising:

4 an encoder operative to encode a plurality of data bits to generate a
plurality of code symbols; and

6 a symbol puncturing element operatively coupled to the encoder and
operative to

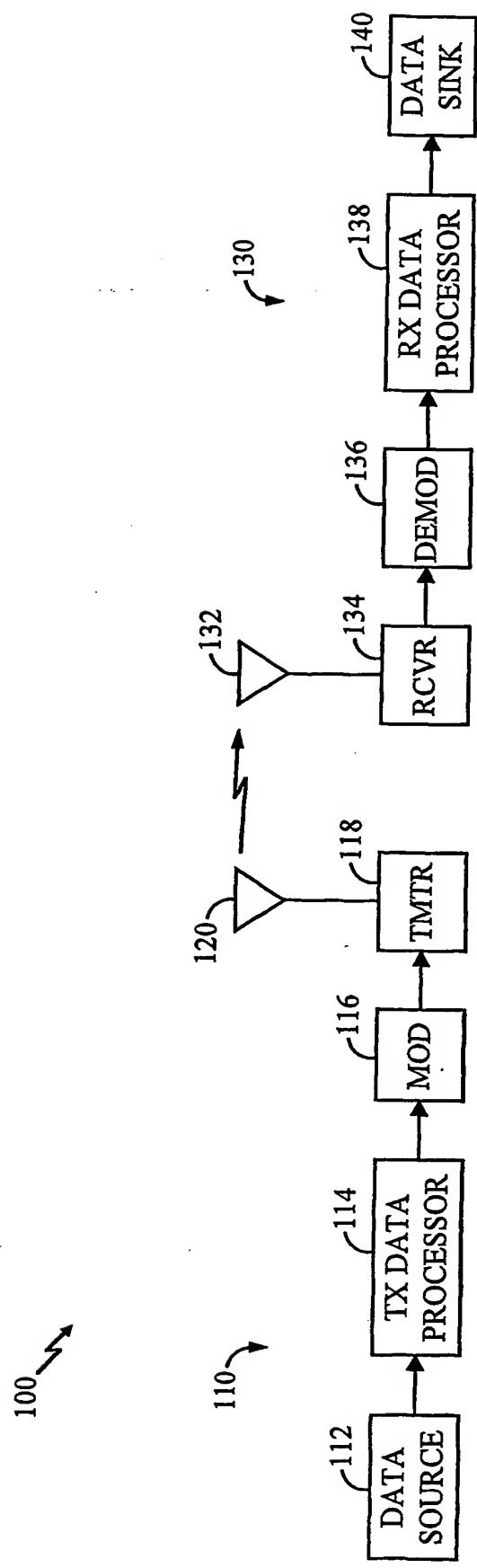
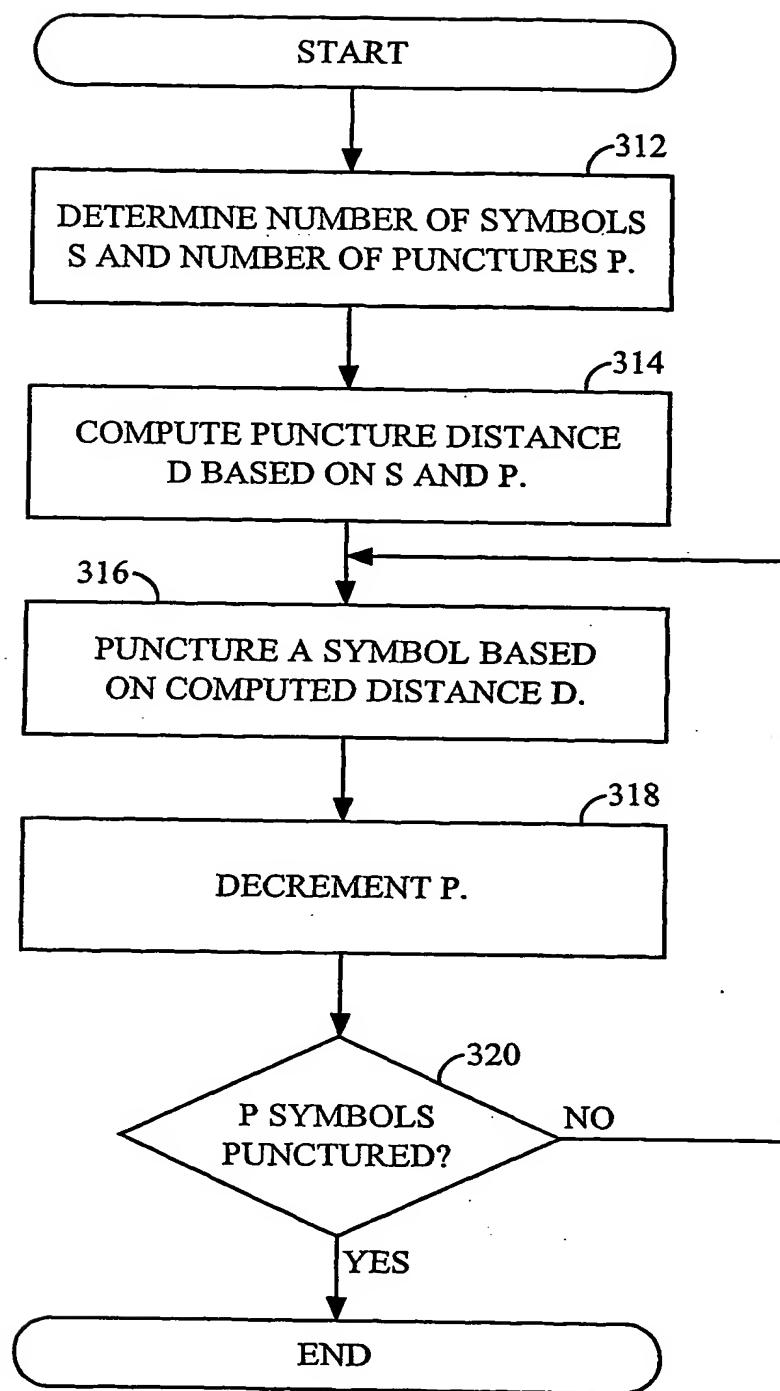


FIG. 1

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(PRIOR ART)

FIG. 3A

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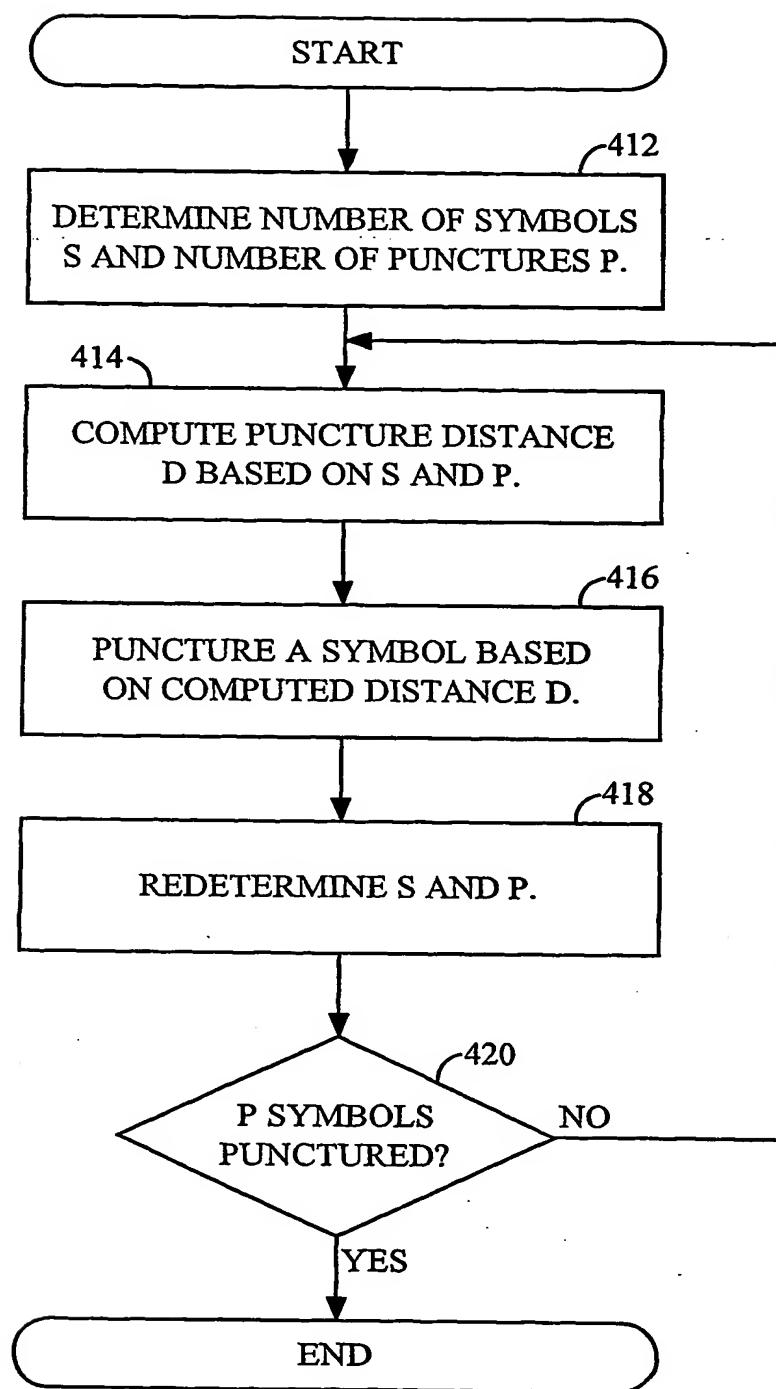
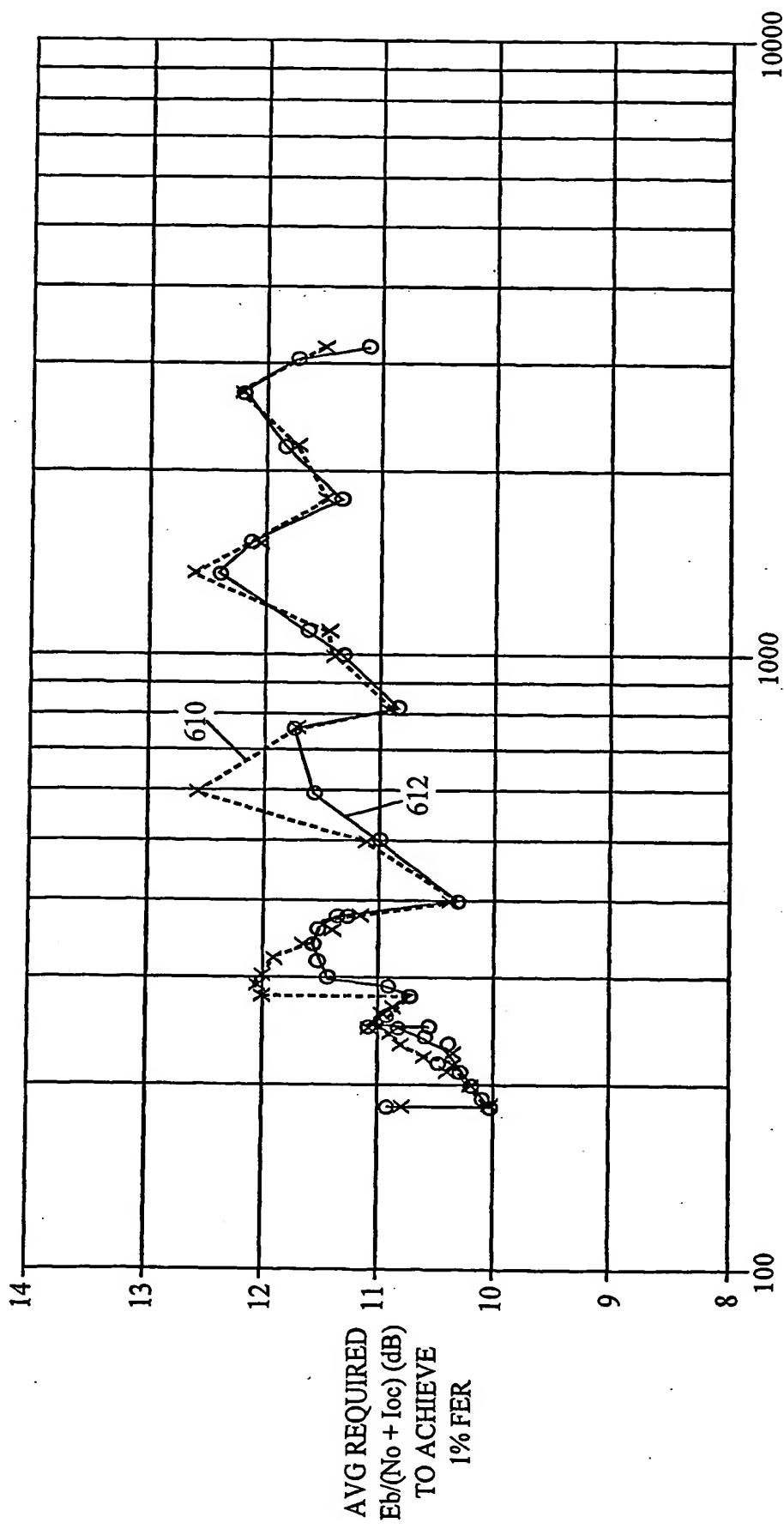


FIG. 4A

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CDMA2000 FORWARD LINK, SCH RC4, 1% FER, VERY SLOW POWER CONTROL,
1 PATH RAYLEIGH FADING MODEL, CENTER FREQUENCY = 2 GHz, $\hat{I}_{\text{or}}/(N_0 + I_{\text{oc}}) = \text{dB}$



DATA BITS + CRC BITS PER FRAME

FIG. 6

INTERNATIONAL SEARCH REPORT

Int'l Application No
PCT/US 01/18252

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H03M13/00 H04L1/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H03M H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E	WO 01 47124 A (KSCHISCHANG FRANK ;RES IN MOTION LTD (CA); MANTHA RAMESH (CA)) 28 June 2001 (2001-06-28) page 35 -page 39 figure 16	1
A	UMTS: "UTRAN, UTRA FDD, multiplexing, channel coding and interleaving description (UMTS xx.04 version 1.0.0)" ETSI, 'Online! February 1999 (1999-02), pages 1-16, XP002181831 Sophia Antipolis, France Retrieved from the Internet: <URL: http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_02/Docs/pdfs/RP-99026.pdf> 'retrieved on 2001-11-01! page 10	1,2,4,6

Further documents are listed in the continuation of box C.

Patent family members are listed in annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search

Date of mailing of the international search report

2 November 2001

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/18252

Patent document cited in search report		Publication date		Patent family member(s)		Publication date
WO 0147124	A	28-06-2001	AU WO	2335001 A 0147124 A2		03-07-2001 28-06-2001
WO 0021234	A	13-04-2000	AU BR WO EP	6332699 A 9914353 A 0021234 A1 1119934 A1		26-04-2000 26-06-2001 13-04-2000 01-08-2001